

Iberian **AtLAST** days 2026

June 4<sup>th</sup>



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## Advancing W-Band KIDs for Millimeter-Wave Astronomy

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**Victor Rollano,**  
on behalf of the Superconducting Technologies Group

Centro de Astrobiología (CSIC-INTA)

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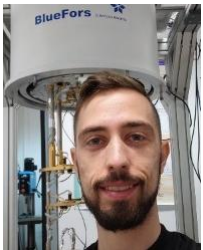


# Outline

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- ✓ **Our team: *Who we are?***
- ✓ **Scientific motivation and detector requirements**
- ✓ **Kinetic Inductance Detectors**
  - *Basics on superconductivity*
  - *How do KIDs detect radiation?*
  - *KIDs for the W-Band*
- ✓ **Implementation**
- ✓ **W-band KID development and results**

# Who we are?



David  
Rodriguez



Maria Teresa  
Magaz



Victor  
Rollano



Alejandro  
Pascual



Daniel Granados



Francisco  
Najarro



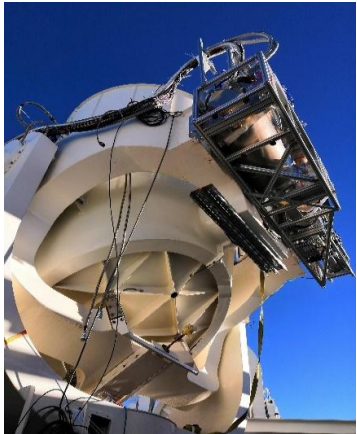
Jesús Martín-  
Pintado



Alicia Gómez  
[agomez@cab.inta-csic.es](mailto:agomez@cab.inta-csic.es)

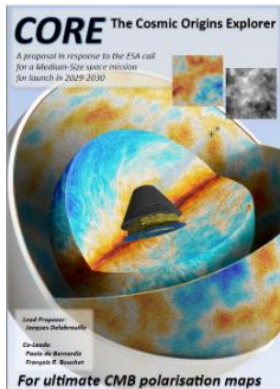


# Who we are?



## *Developing Superconducting Devices for 10 years!!*

- Demonstrators from mm to FIR wavelengths.
- Large-format Array demonstrators.
- Responsivity and sensitivity characterization.
- Polarimetry characterization.
- Participation in Earth-based observatories.
- Pushing KIDs to dark matter....



# KIDsNET – maturing KIDs technology

*Development of state-of-the-art technologies requires coordination and collaboration of multidisciplinary groups*

## The Spanish Thematic Network "KIDsNET: Maturing KIDs technology"

*RED2022-134839-T funded by Spanish MCIN/AEI/10.13039/501100011033*

Join and coordinate resources with the common objective of maturing and advancing the KIDs readiness level in Spain



*A. Gómez F. Najarro*



*D. Granados*



*J. J. Díaz*



*J. D. Gallego*



*L. M. de la Fuente*



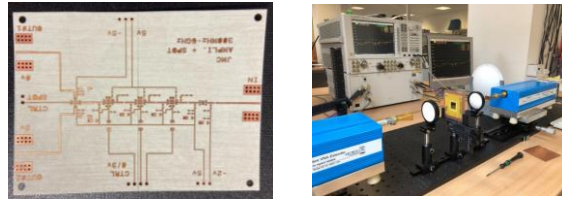
# KIDsNET – maturing KIDs technology



Luisa de la Fuente  
Beatriz Aja  
Enrique Villa



Working with CAB for 6 years!!



Eduardo Artal  
Juan Pablo Pascual

- MW design from mm to fir
- Quasi-optical characterization
- RF board for readout

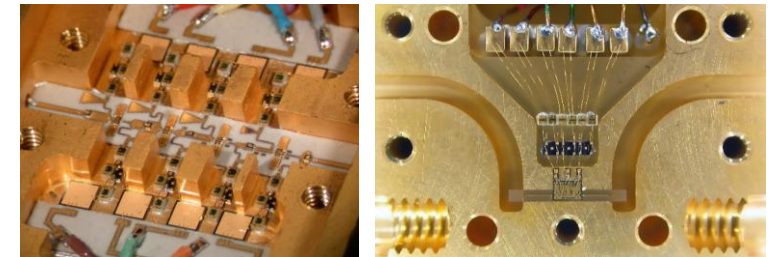
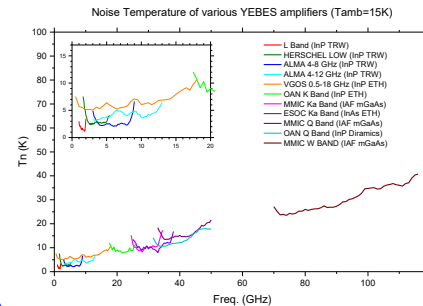


## Observatorio Astronómico de Yebes

- State-of-the-art cryogenic InP HEMT amplifiers
- ALMA, Herschel, ESO, IRAM, JPL, PRIMA?

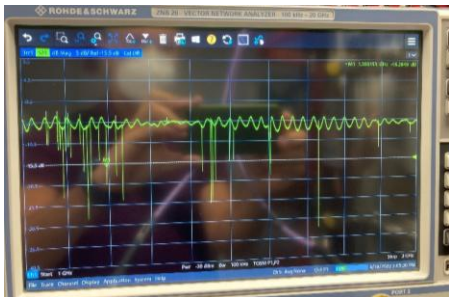


J. Daniel Gallego  
I. López-Fernández  
Carmen Diez  
Inma Malo  
Ricardo I. Amils  
Alberto García



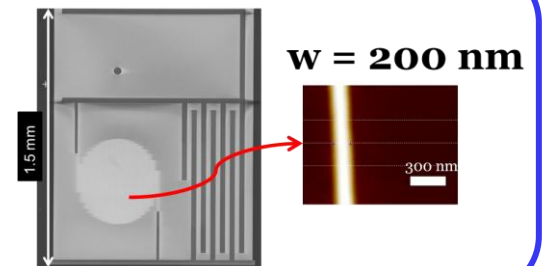
## Instituto de Astrofísica de Canarias: Departamento de Instrumentación

- FPGA-based multipixel readout system
- ADR Fridge



## Nanofabrication facilities

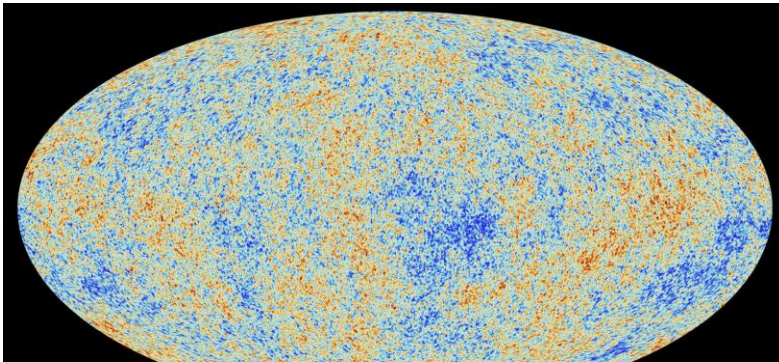
- Robust fabrication process
- SNSPDs



# Scientific motivation

mm-wave astronomy deals with extremely faint signals

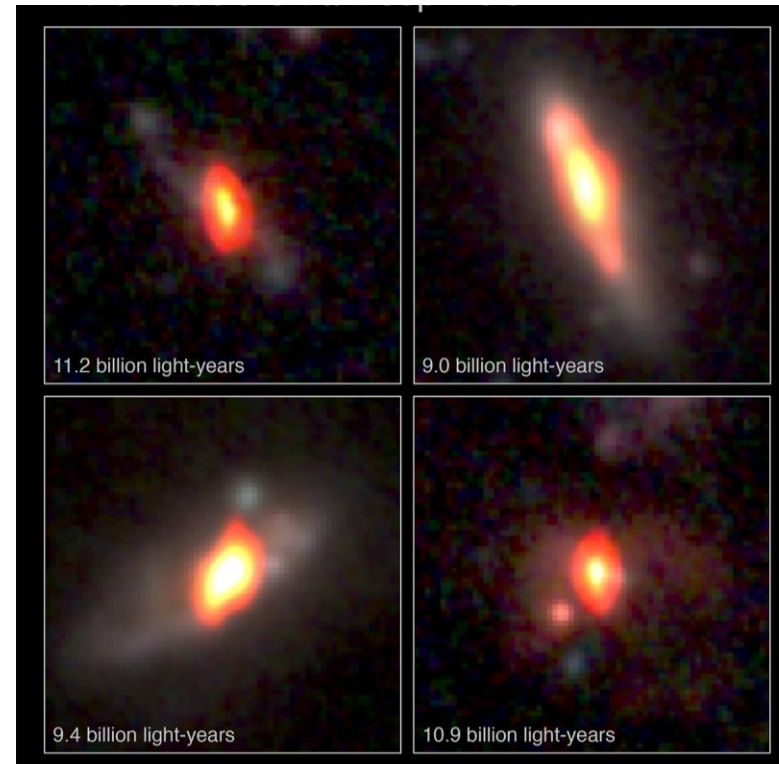
- CMB tiny fluctuations
- Cold dust and diffuse emission
- Faint and distant sources
- Cosmological redshift



*Cosmic Microwave Background (mm / submm)*



*Cold dust and diffuse emission (submm/FIR)*

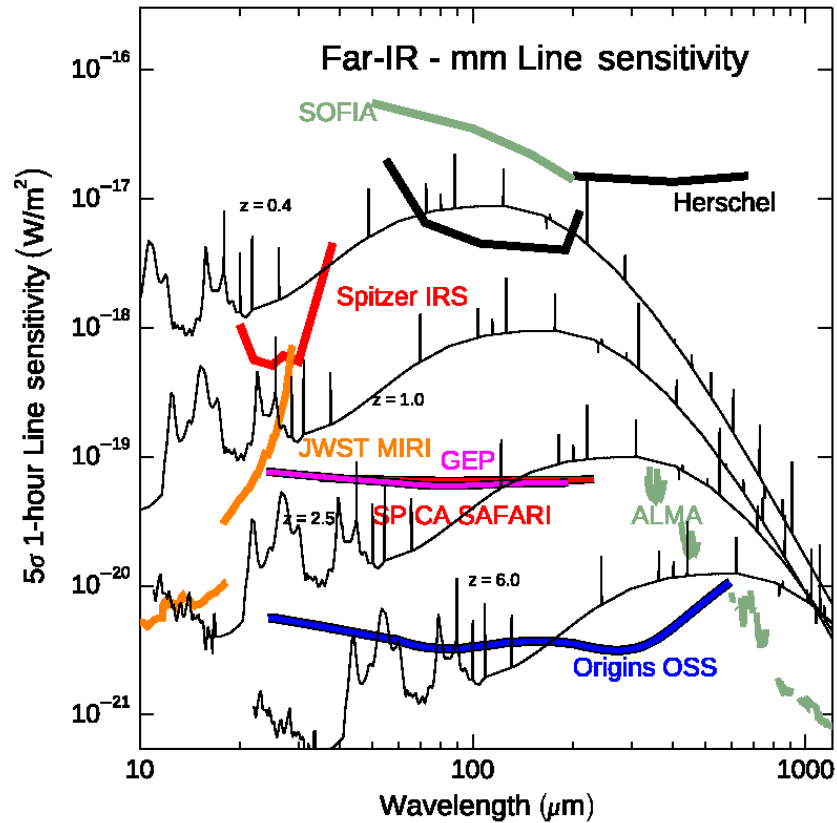


*Early universe observations (mm/submm)*

# Detector requirements for mm-wave astronomy

I. Ultra-low noise  $\Rightarrow$  Lower NEP  
*Detection of fainter signals*

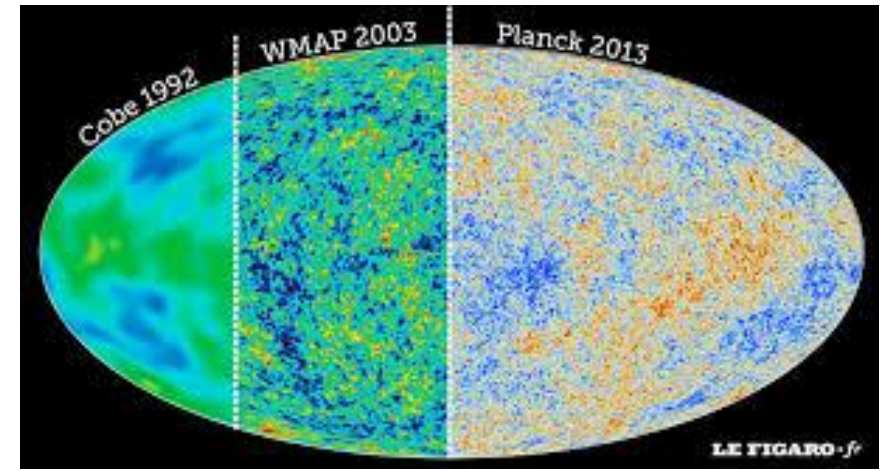
II. Large number of pixels  $\Rightarrow$  Larger field of view  
*Mapping speed  $\propto N_{det}$*



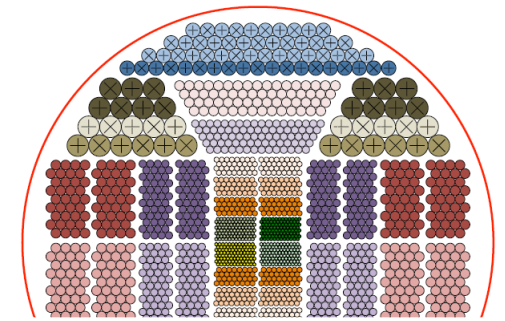
Noise  
 Equivalent  
 Power

$$NEP = \frac{P_{sig} \sqrt{\tau}}{SNR}$$

C. M. Bradford, et al.,  
 J. Astron. Telesc. Instrum.  
 Syst. 7(1), 011017 (2021)



Planck : 63 detectors



CORE concept  
 $\sim$  2100 detectors

# From conventional detectors to superconducting arrays

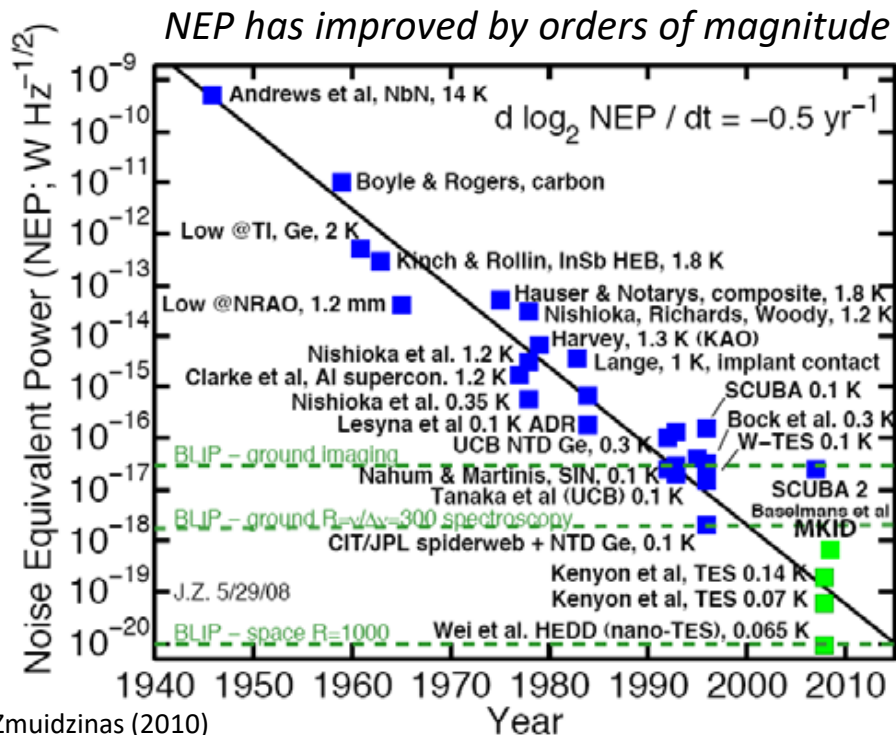
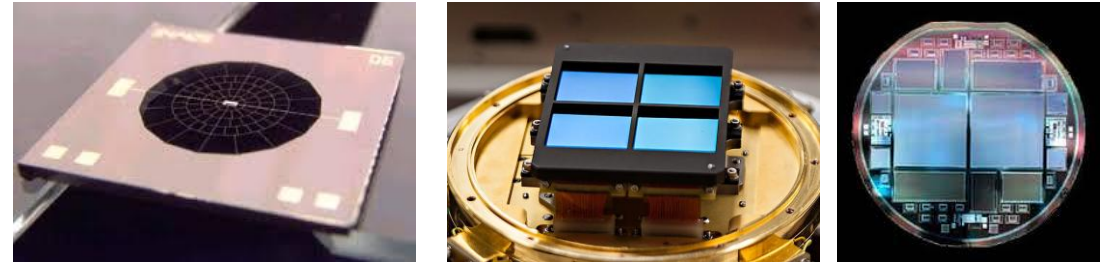
## REQUIREMENTS

- Ultra-low noise
- Large detector arrays
- Cryogenic compatibility
- Multiplexed readout

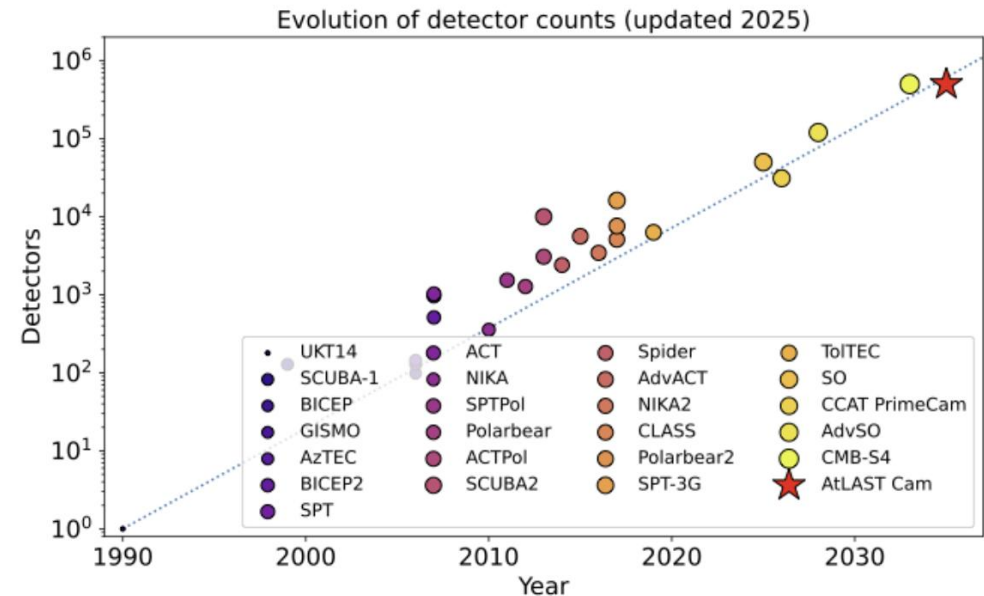


## Conventional detector technologies

*Bolometers, photoconductors, HEMTs, CCDs...*



## Detector array size is rapidly increasing



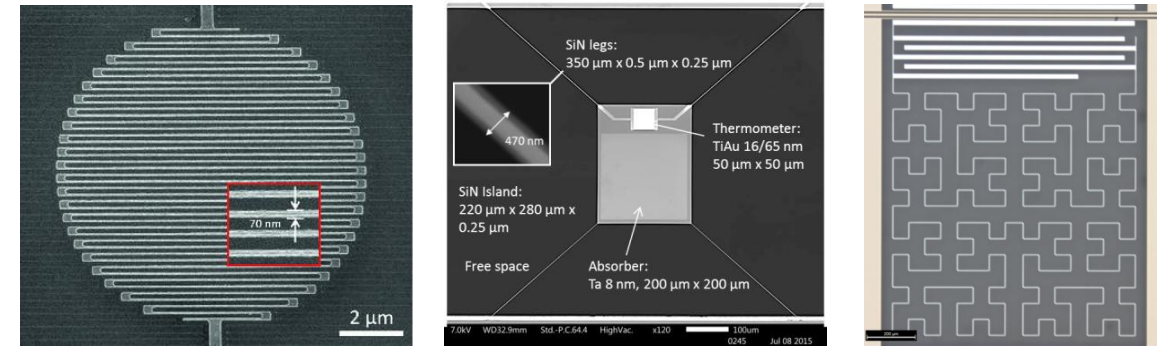
# Superconducting detectors for ultra-sensitive large arrays

## REQUIREMENTS

- Ultra-low noise
- Large detector arrays
- Cryogenic compatibility
- Multiplexed readout

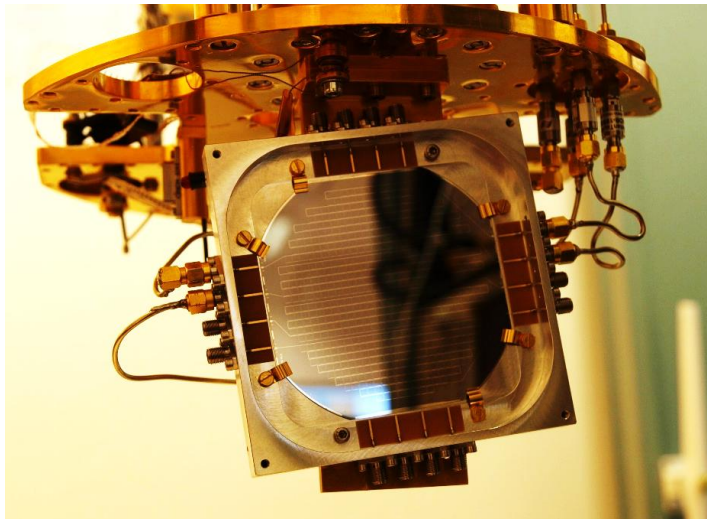


## Superconducting detectors

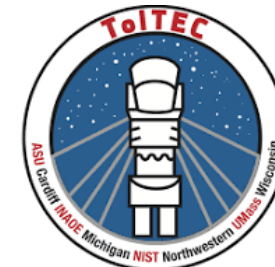


SIS, TES, KIDs, SNSPDs

## *Kinetic Inductance Detectors (KIDs)*

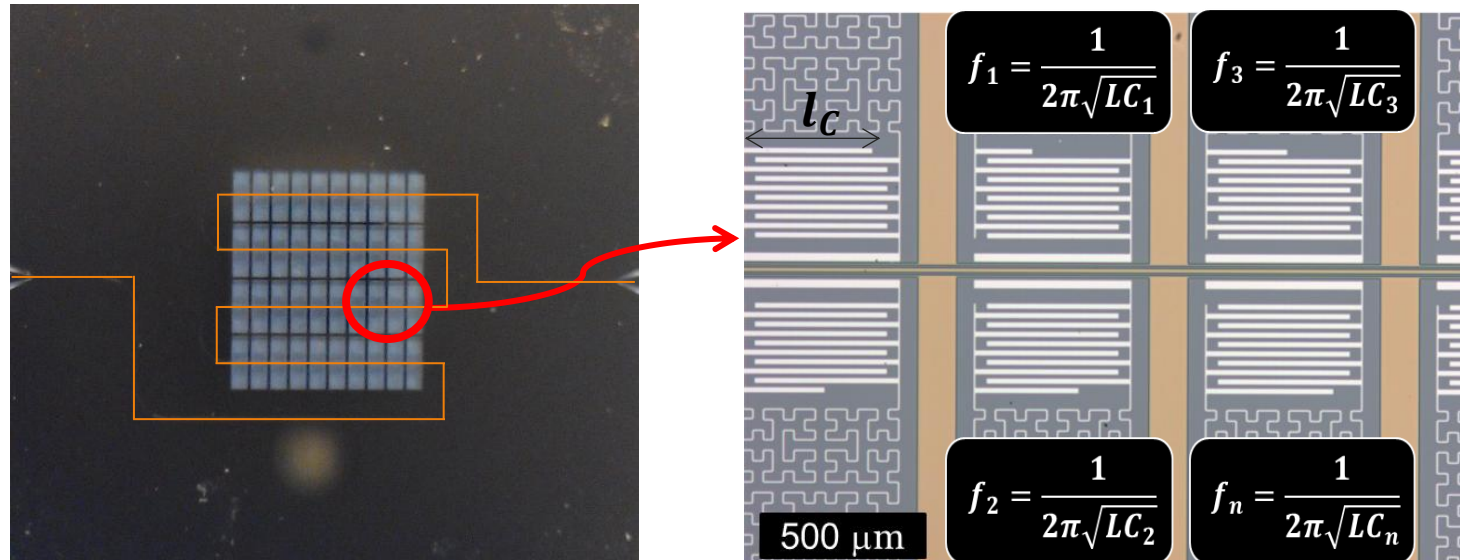
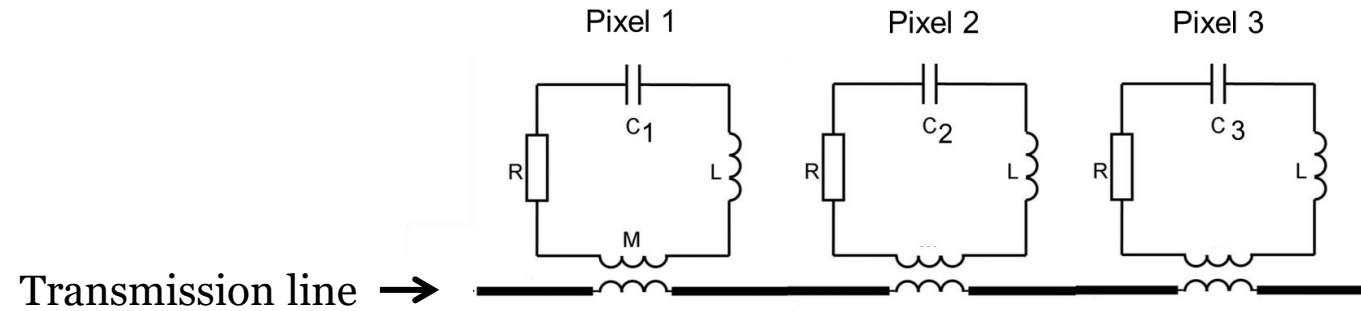


- State-of-the-art sensitivity
- Broadband detection
- Intrinsically multiplexable
- Reduced cryogenic wiring



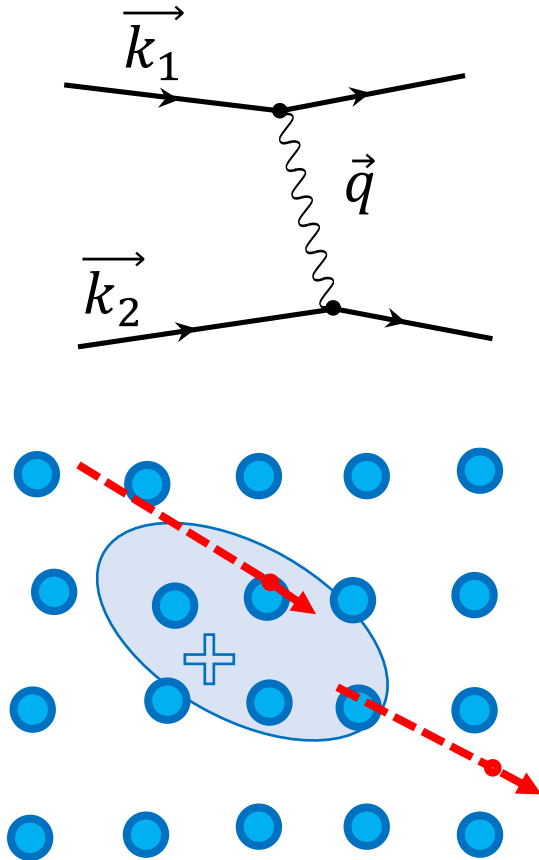
# KIDs are intrinsically multiplexable

Multiple (~1000) KIDs coupled to a single transmission line

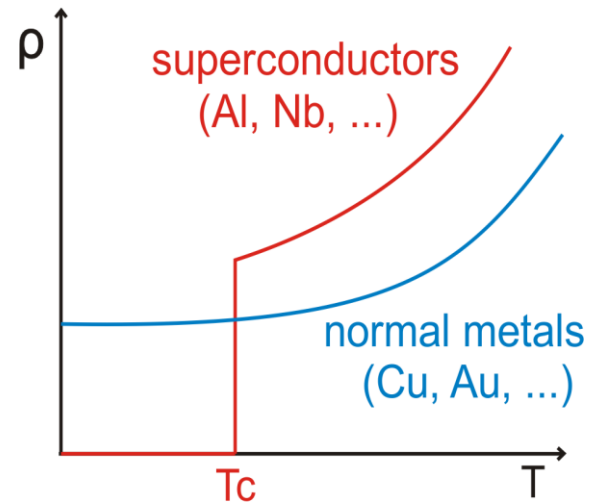


# Basics on superconductivity

## Cooper pairs

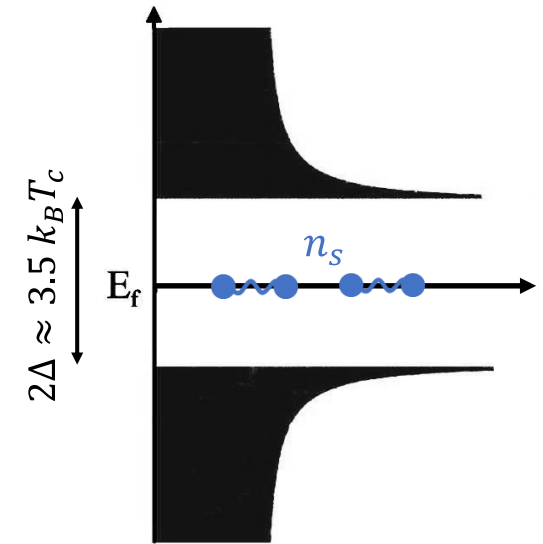


## Zero DC resistance below $T_c$



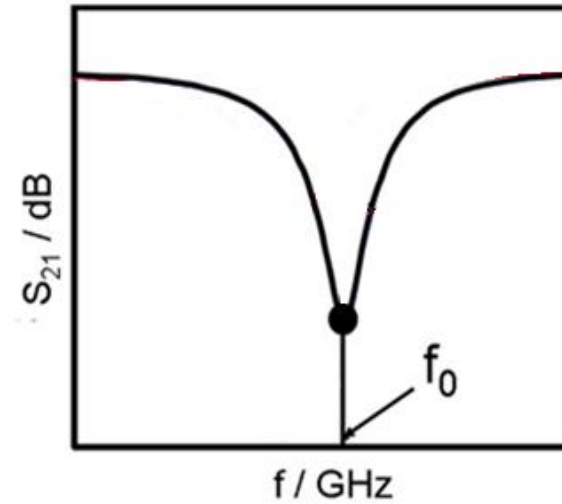
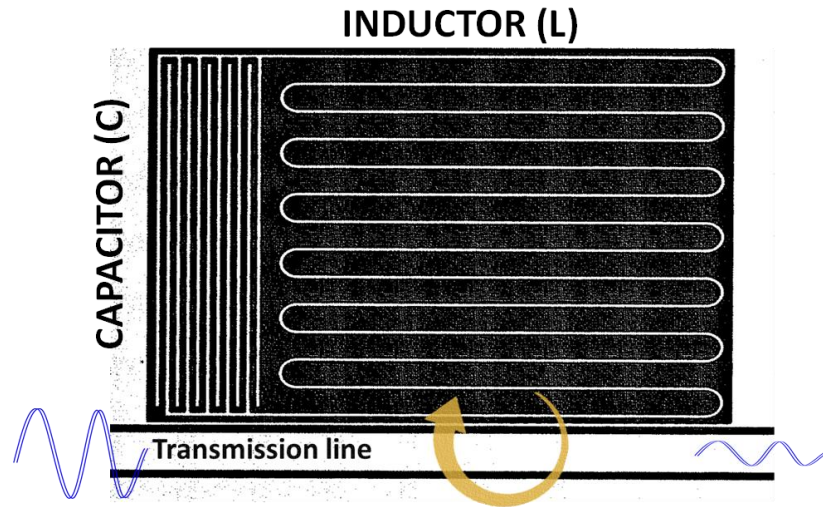
$T < T_c$   
Zero Resistance

## Energy gap ( $\Delta$ )



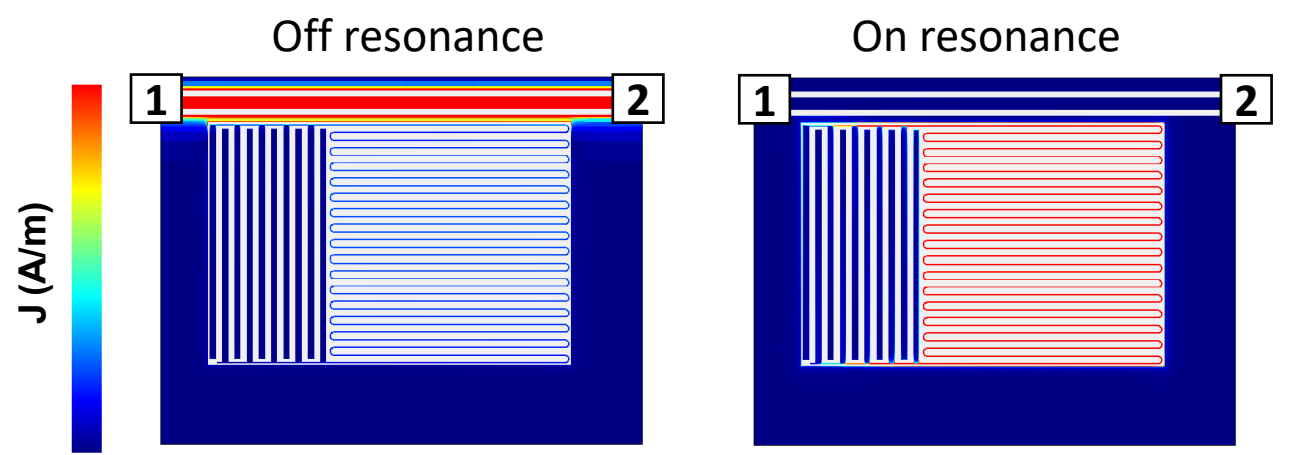
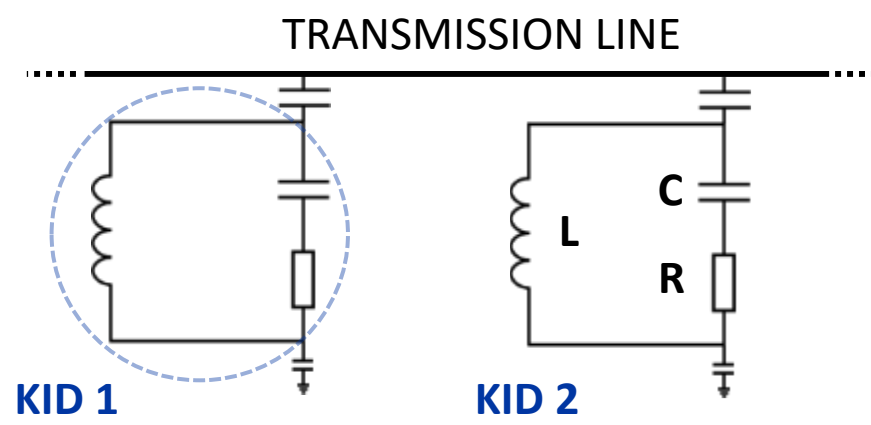
Material	$T_c$ (K)	$\Delta$ (meV)	$2\Delta$ (GHz)
Aluminum	1.2	0.18	90
Niobium	9.3	1.5	725
NbTiN	15	2.5	1200

# KIDs are superconducting microwave resonators

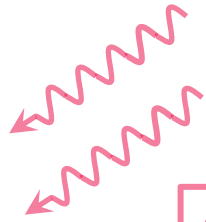
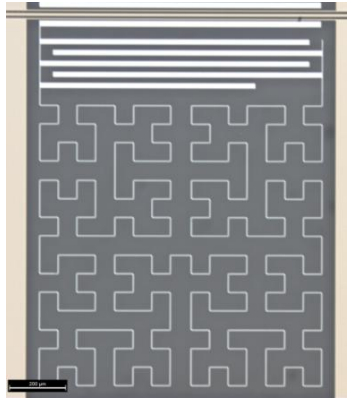


$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

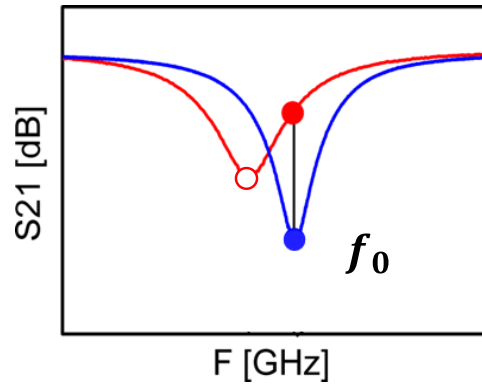
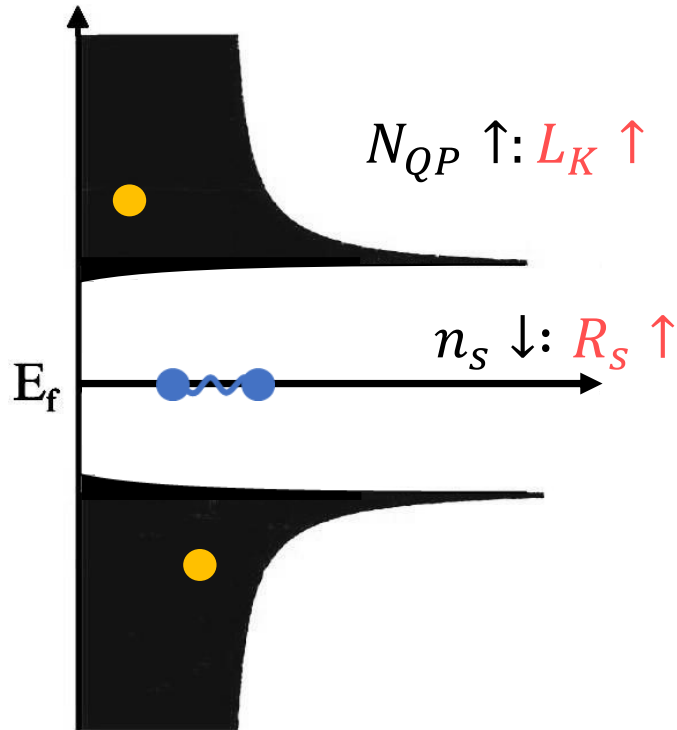
LC Circuit  $\Rightarrow$  Resonator



# How does a KID detect radiation?



$$E_{\text{photon}} > 2\Delta$$



$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$f' = \frac{1}{2\pi\sqrt{L'C}}$$

**Kinetic Inductance:  $L_K$**

Cooper pairs inertia

$$\sigma_2 \approx \frac{n_s e^2}{m^* \omega}$$

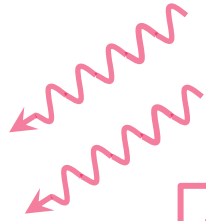
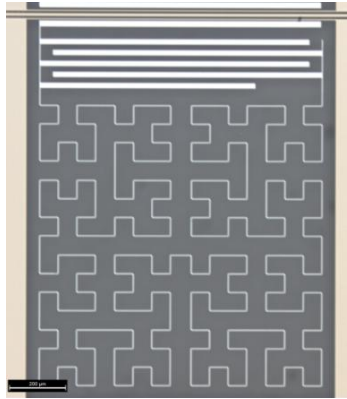
$$\sigma_2 \approx \frac{1}{\omega L_K}$$

System must provide energy to change Cooper pair moment.

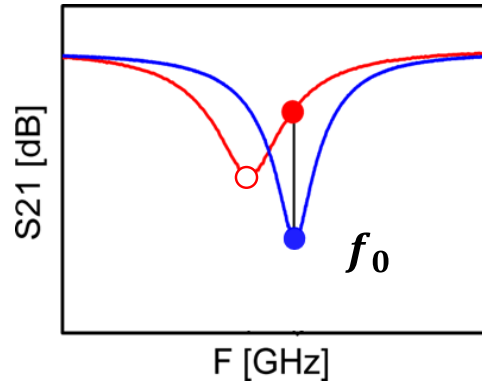
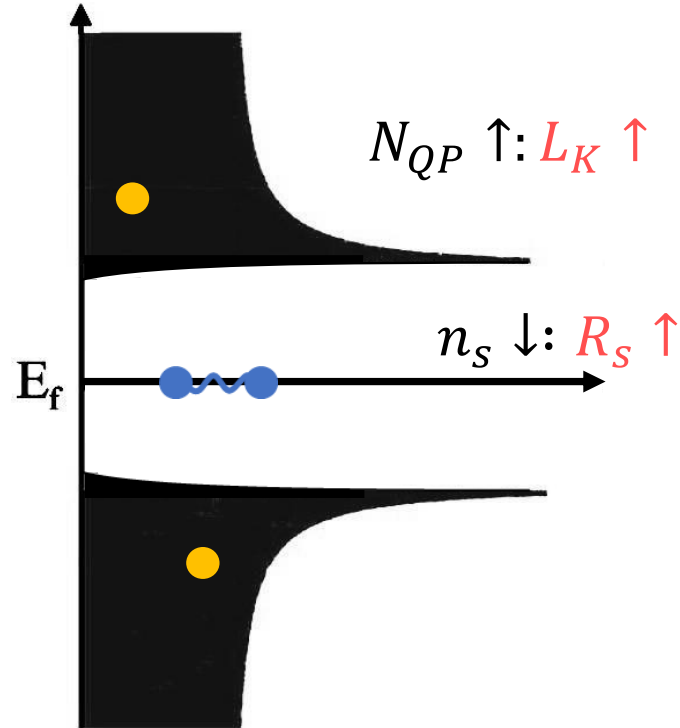
$$n_s \downarrow \quad n_{qp} \uparrow \quad \sigma_2 \downarrow \quad L_K \uparrow$$

**Cooper pair breaking mediates photon detection**

# How does a KID detect radiation?



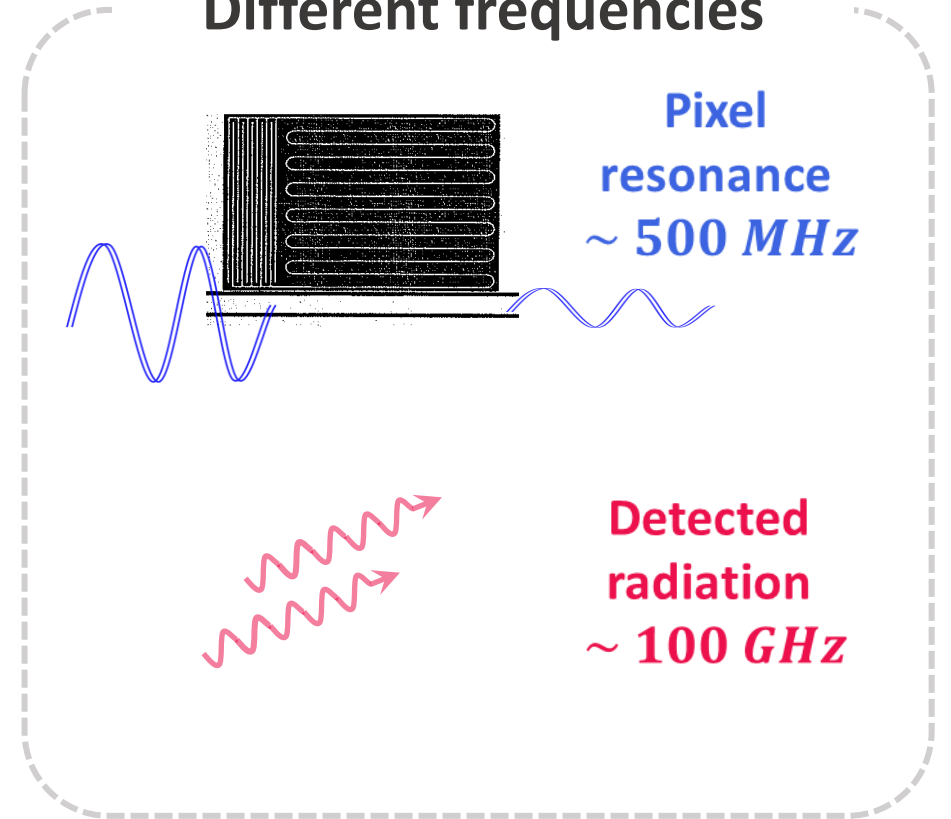
$$E_{\text{photon}} > 2\Delta$$



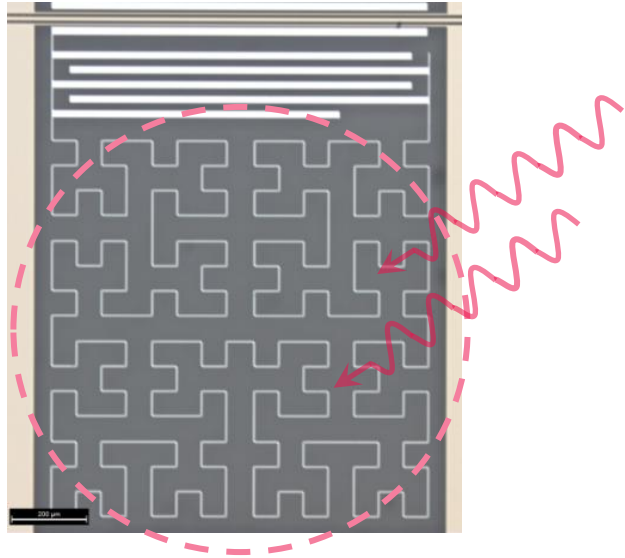
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$f' = \frac{1}{2\pi\sqrt{L'C}}$$

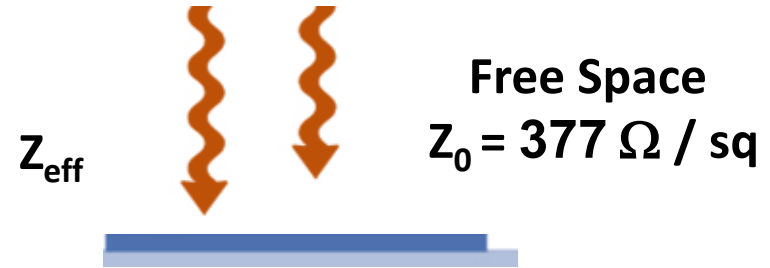
## Different frequencies



# From microwave resonator to mm-wave absorber

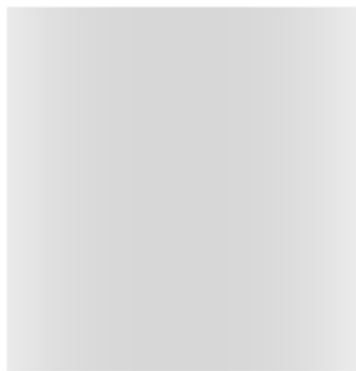


*The inductor is the absorber*

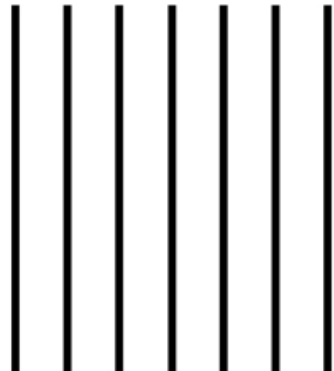


Efficient absorption requires **impedance matching**

$$Z_{\text{eff}} \approx Z_0 \approx 377 \Omega$$



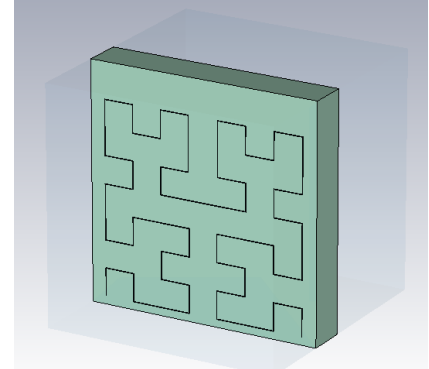
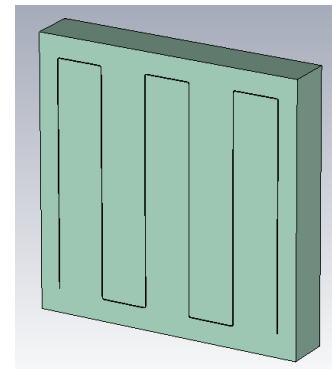
$\lambda \gg s$



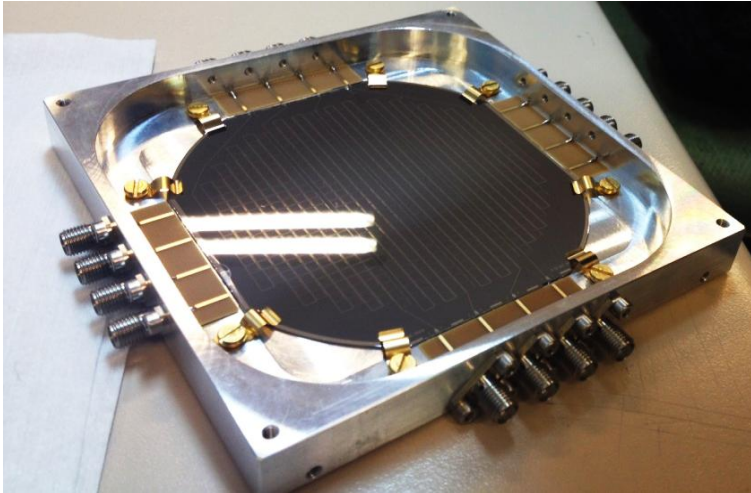
$\lambda \ll s$

$$s < \lambda / 20$$

*Geometry controls polarization selectivity*



# Motivation for W-band KIDs

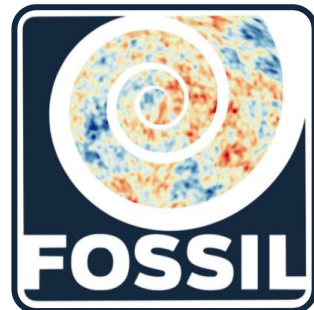
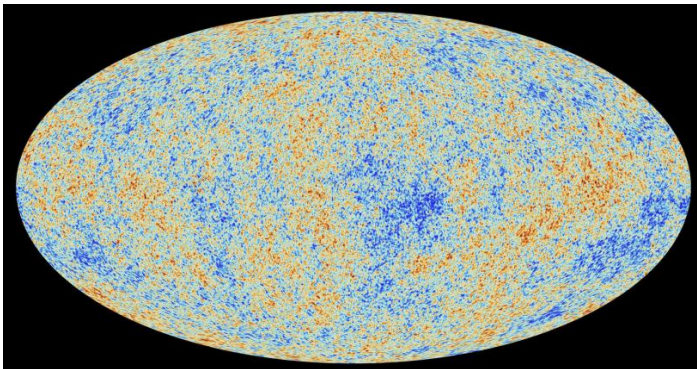


## KIDs for W-band (75 – 110 GHz)

$$h\nu > 2\Delta$$

Detector challenge: superconducting gap engineering

## Cosmic Microwave Background (CMB)

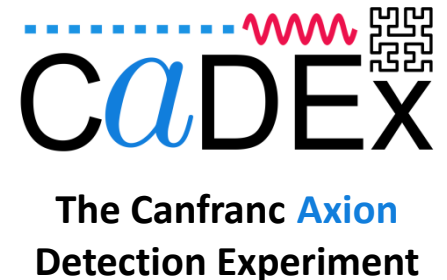


- Lower-frequency CMB bands
- Foreground control

## Dark Matter searches



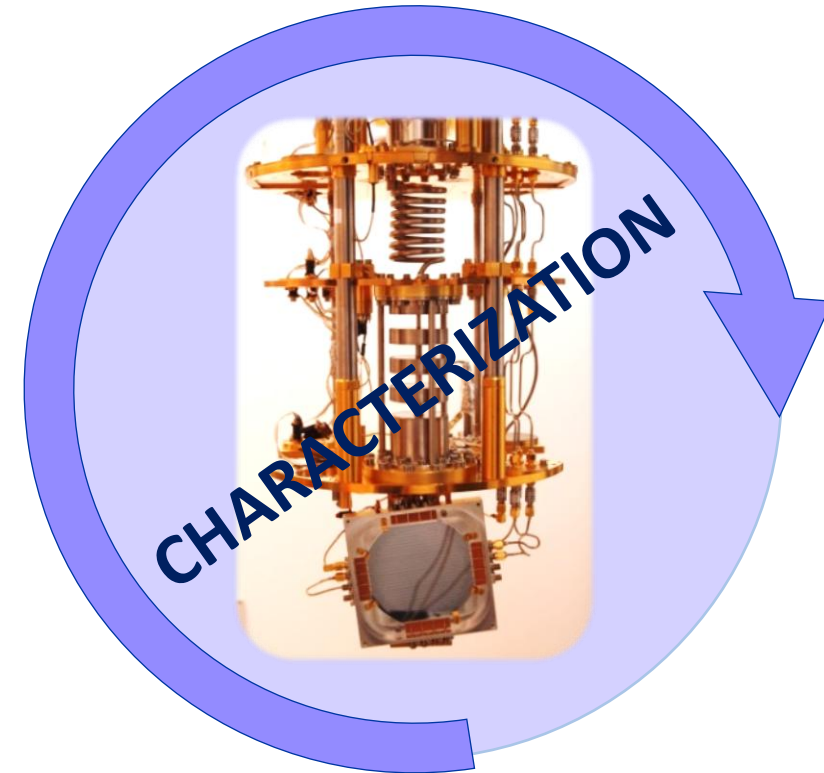
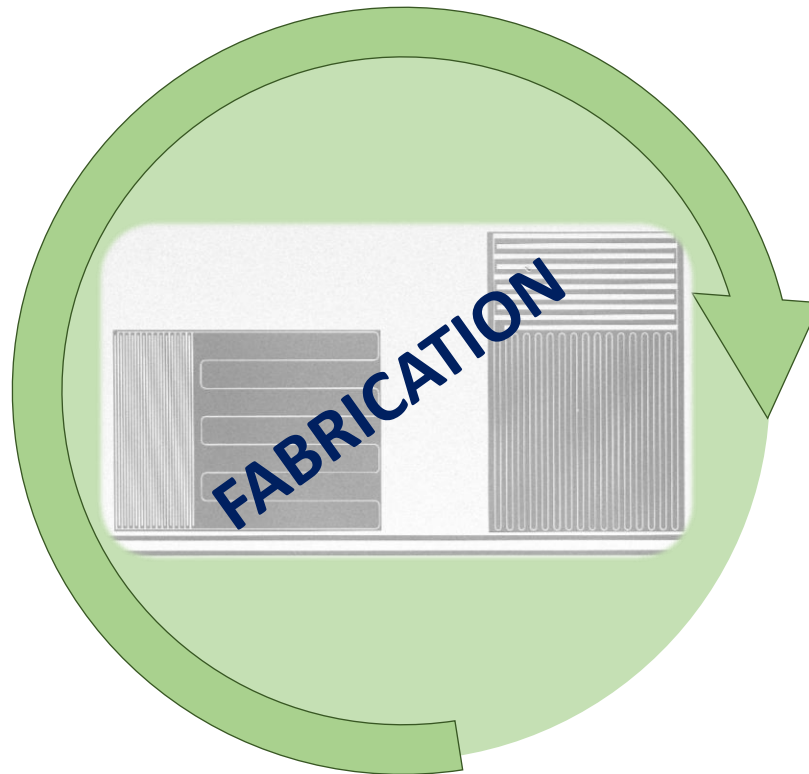
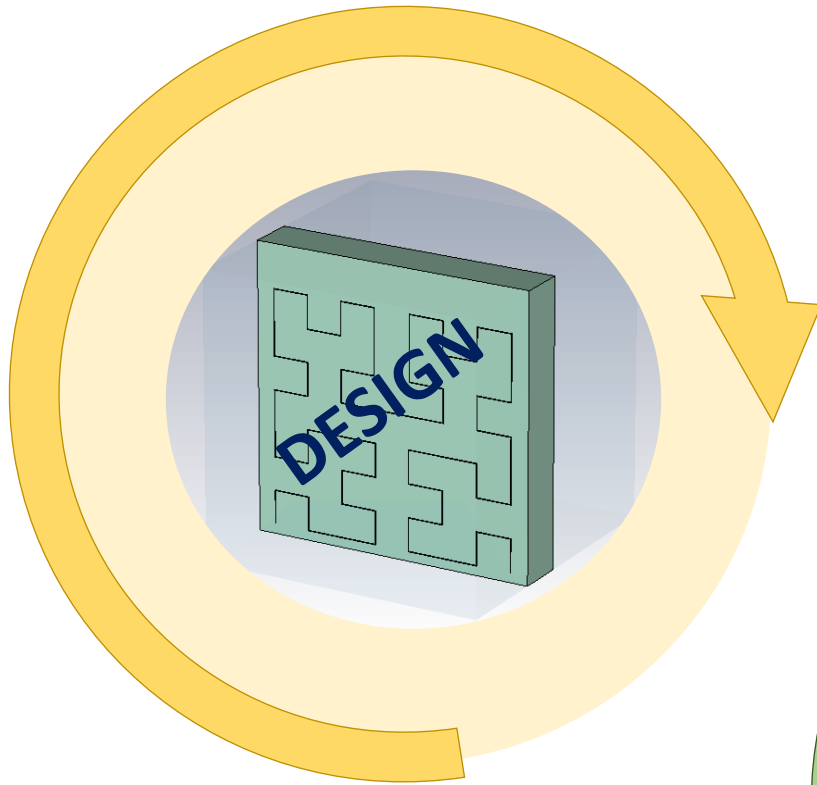
Laboratorio  
Subterráneo  
Canfranc



- Beyond Standard-Quantum-Limit
- Covering the post-inflation mass range (W-band)

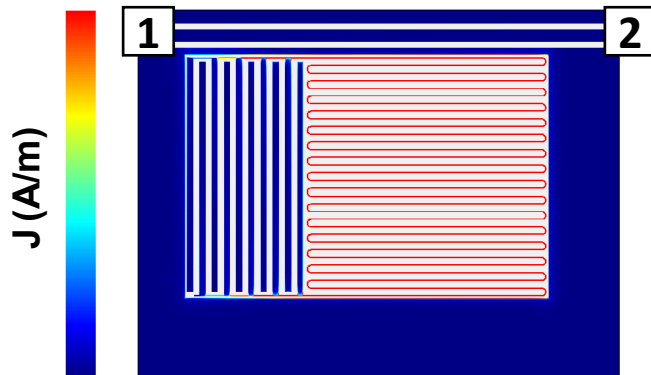
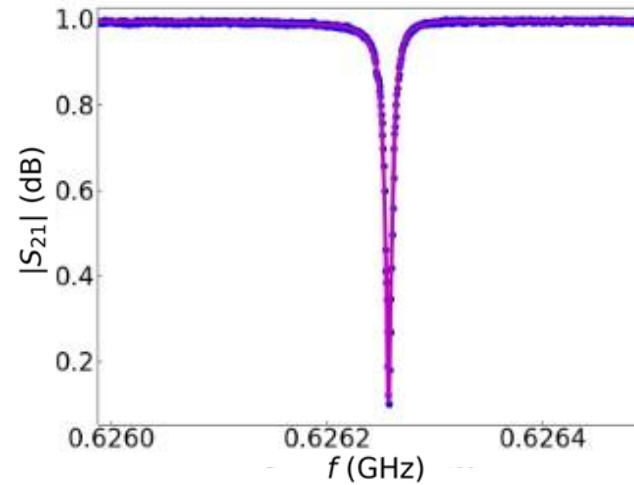
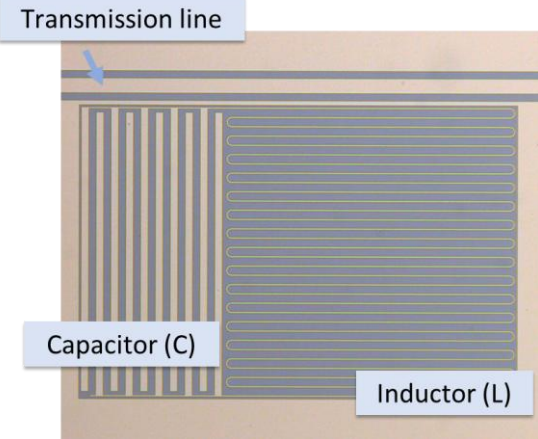
# Facilities and resources

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# Implementation

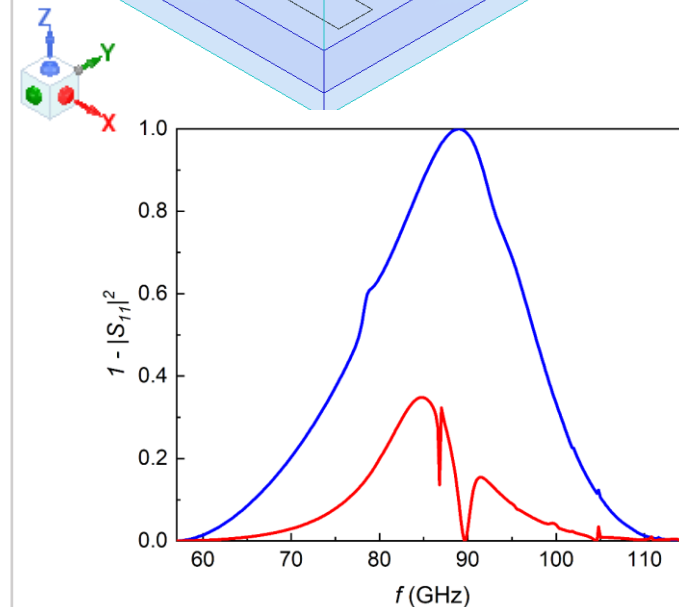
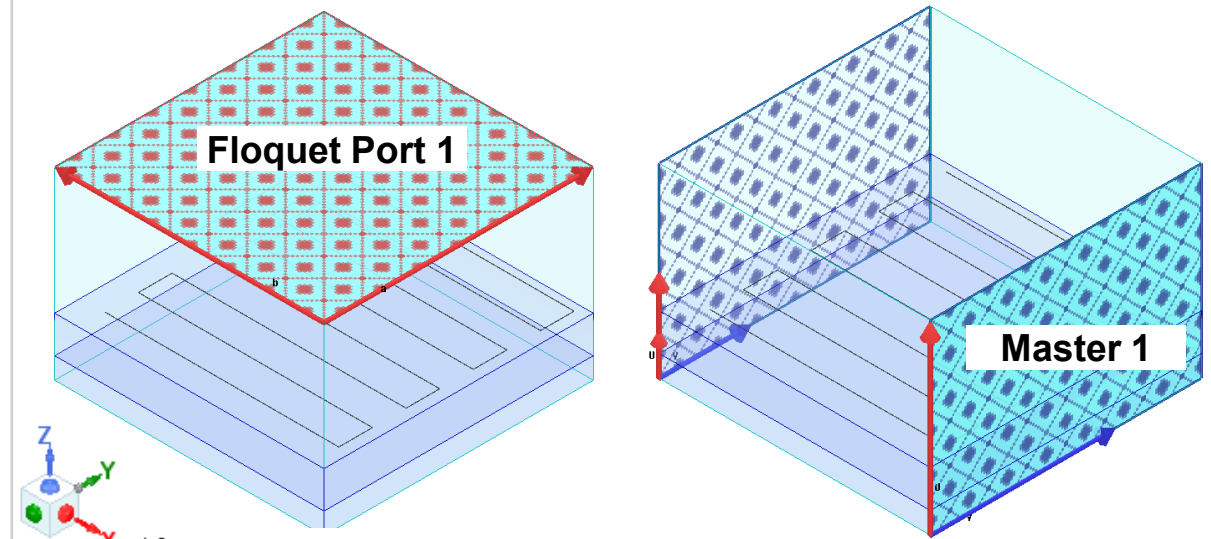
## Read-out Frequency



Sonnet Software:

- ✓ Resonance frequency
- ✓ Coupling quality factor
- ✓ Current distribution

## Quasi-Optical Frequency



HFSS / CST  
simulation suites:  
✓ Absorption response

# Implementation



**Removing surface oxide**

Si Substrate

HF 1% bath

**Depositing the superconducting material**

Al 20 nm Ti 10 nm

Sputtering

**Transfer the design to the resist**

Resist

Laser Writer Lithography

**Transfer the design onto the metal**

Wet Etching

**Removing the resist**

Stripping

- Cleaning
- Bonding

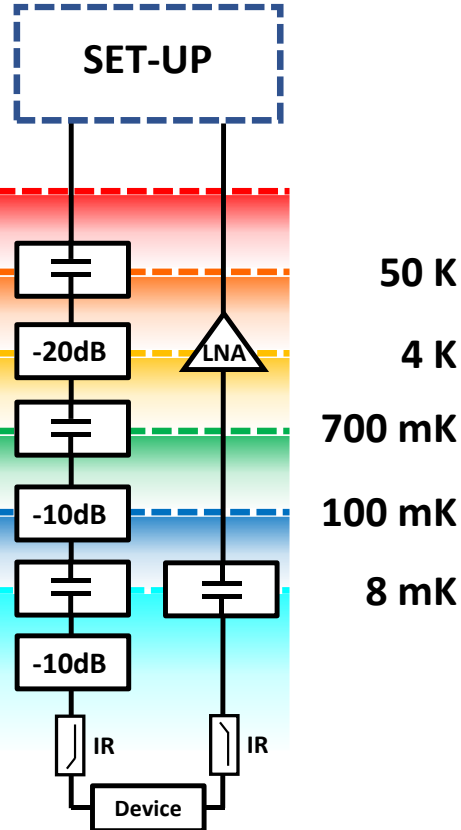
**Final device**

# Implementation

## He<sup>3</sup>/He<sup>4</sup> Dilution Refrigerator



$T \sim 8 \text{ mK}$

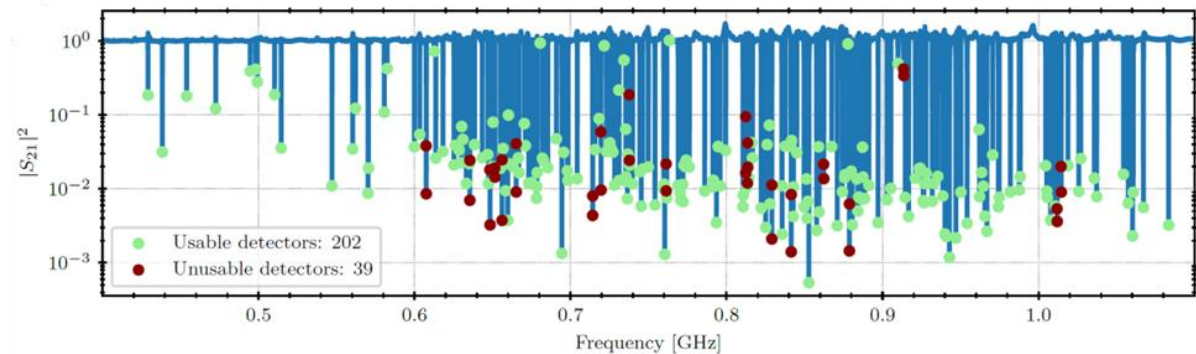


## Multipixel microwave readout system



### Multipixel characterization set-up:

- Eight DAC / ADC channels each capable of measuring 1023 tones simultaneously: **Noise correlation**
- External demodulation synchronization
- Fully portable system



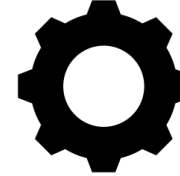
# W-band KID development and results

## Superconducting gap engineering



### GOAL

Set the gap for W-band pair breaking



### APPROACH

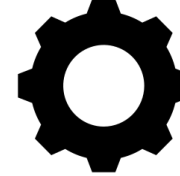
Titanium / Aluminium bilayer absorber

## Pixel absorber geometry



### GOAL

Control polarization  
Maximize absorption



### APPROACH

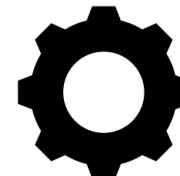
Cross-polarization sources identification

## Detector performance



### GOAL

Characterize detector figure-of-merit (NEP)



### APPROACH

Cryogenic MW characterization in low and high backgrounds

# Titanium / Aluminium adsorber – first iteration

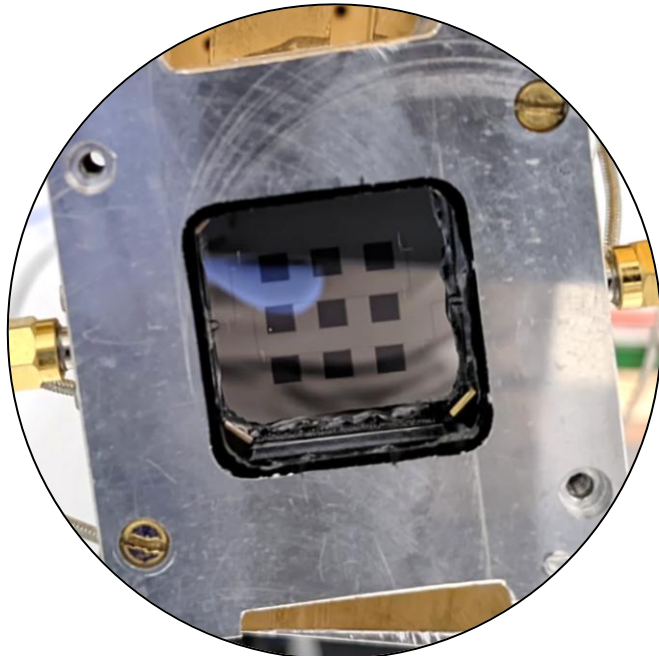
Axion signature is linearly polarized: *Development of on-chip polarimeter for W-band*



*Ti/Al detection system prototype*



**9 x 9 Ti/Al pixels on chip polarimeter demonstrator**



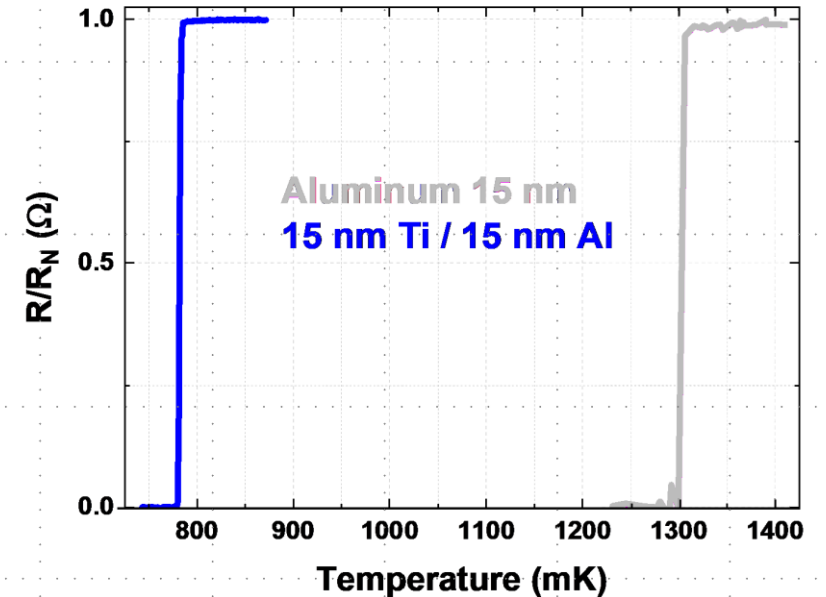
**Titanium / Aluminum  
bilayer**

15 nm Al ( $T_c \approx 1.2$  K)

15 nm Ti ( $T_c \approx 0.4$  K)



$T_c = 780$  mK  
70 GHz low cut off



*Reaching absorption in the W-band*

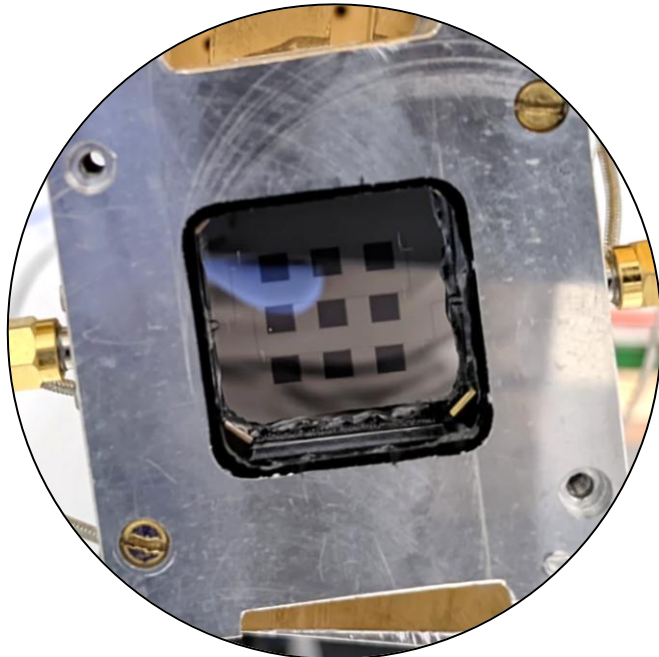
# Titanium / Aluminium adsorber – first iteration

Axion signature is linearly polarized: *Development of on-chip polarimeter for W-band*

*Ti/Al detection system prototype*



**9 x 9 Ti/Al pixels on chip polarimeter demonstrator**



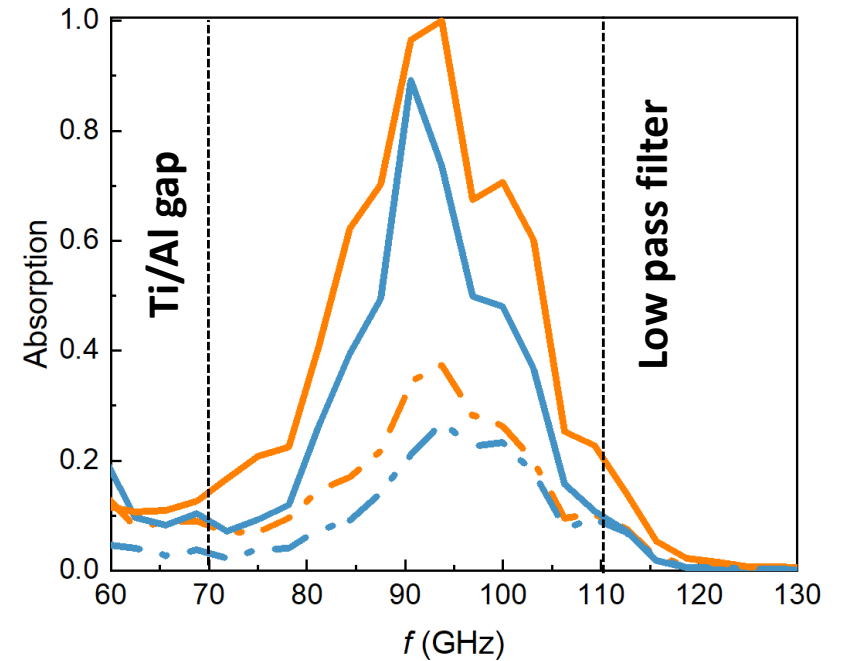
**Titanium / Aluminum  
bilayer**

15 nm Al ( $T_c \approx 1.2$  K)

15 nm Ti ( $T_c \approx 0.4$  K)



$T_c = 780$  mK  
70 GHz low cut off



**Reaching absorption in the W-band** ✓

# Titanium / Aluminium adsorber – first iteration

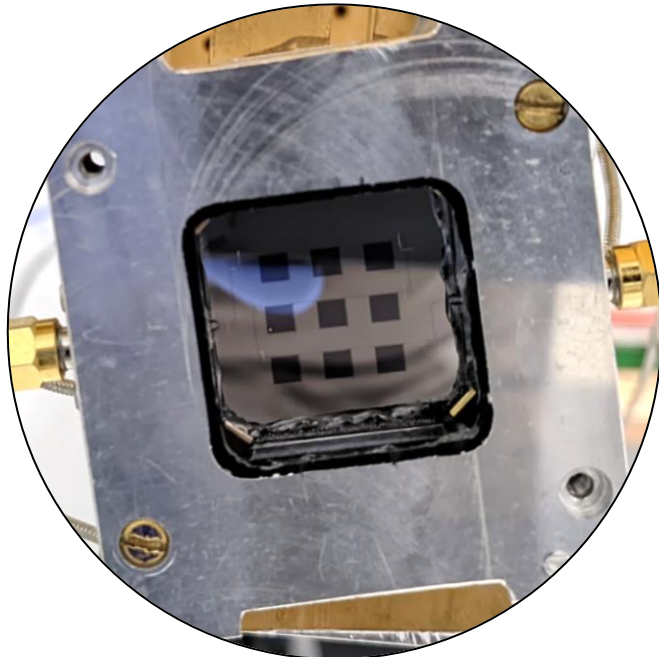
Axion signature is linearly polarized: *Development of on-chip polarimeter for W-band*



*Ti/Al detection system prototype*



**9 x 9 Ti/Al pixels on chip polarimeter demonstrator**



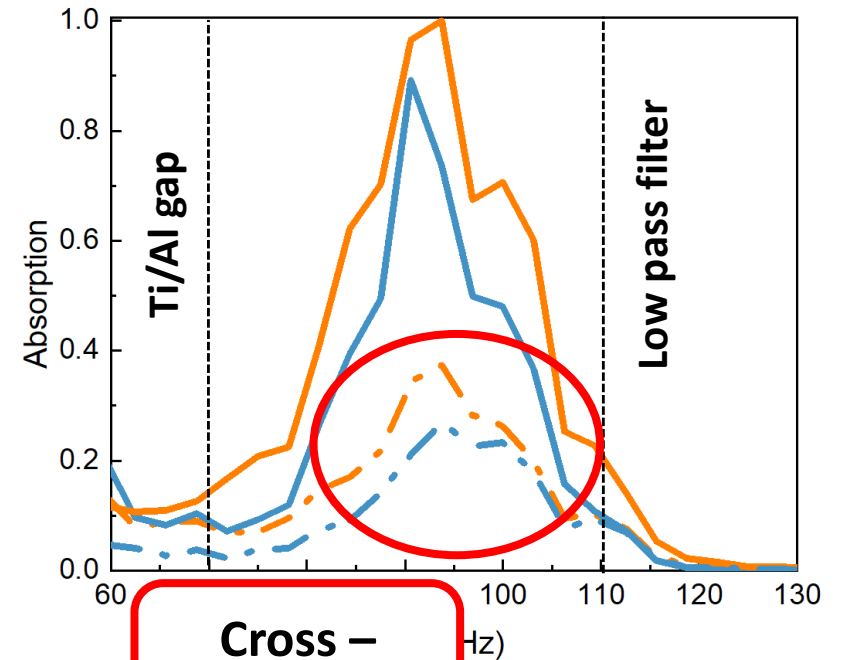
**Titanium / Aluminum  
bilayer**

15 nm Al ( $T_c \approx 1.2$  K)

15 nm Ti ( $T_c \approx 0.4$  K)



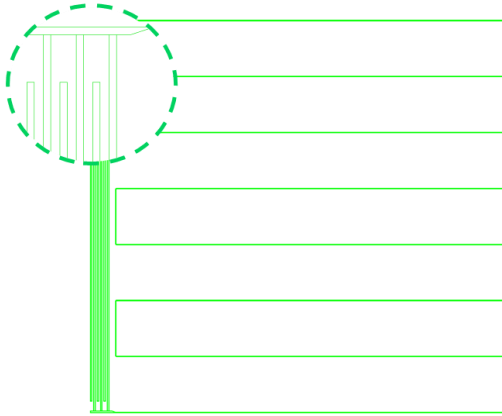
$T_c = 780$  mK  
70 GHz low cut off



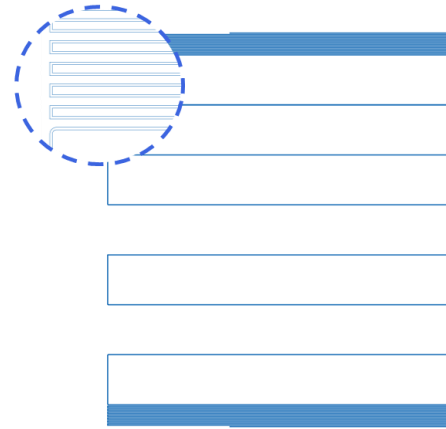
**Reaching absorption in the W-band**

# Titanium / Aluminium adsorber – first iteration

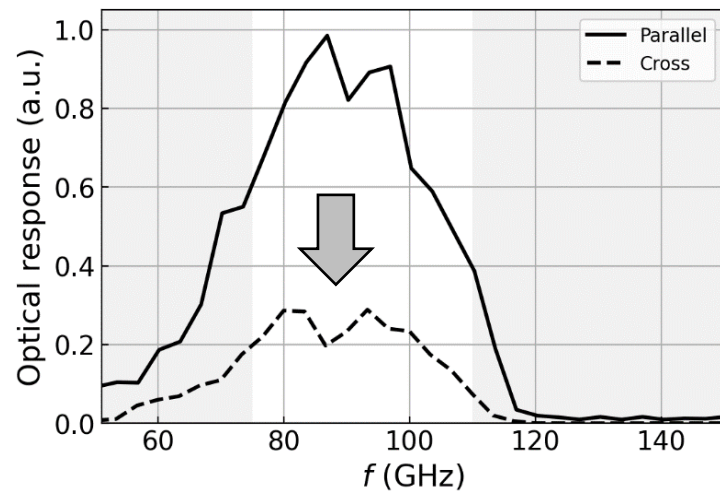
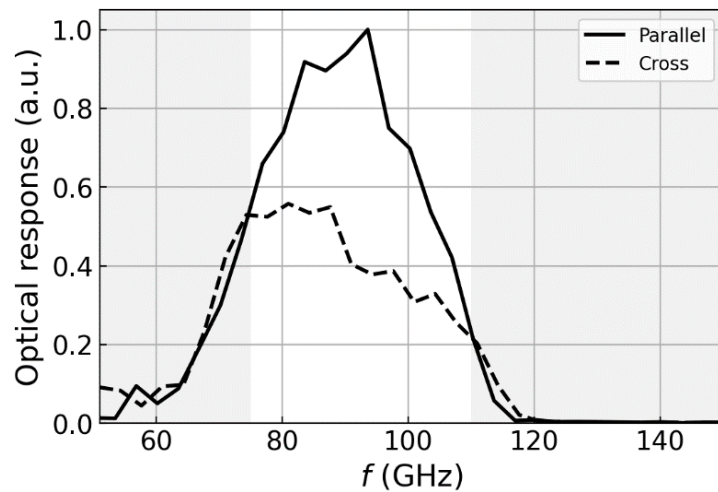
## Solving cross-polarization issues



LER : Lumped Element Resonators



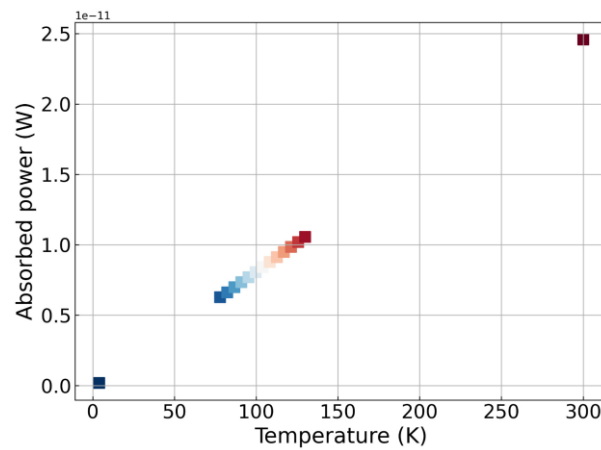
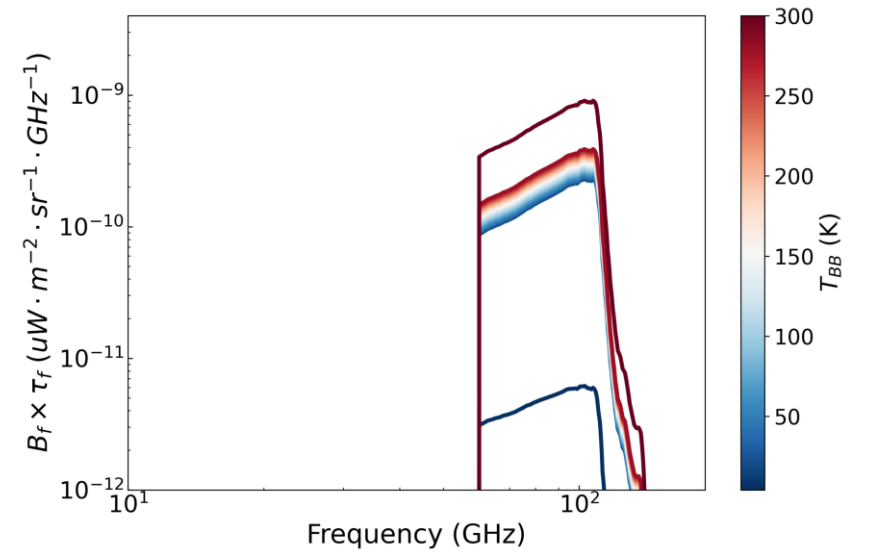
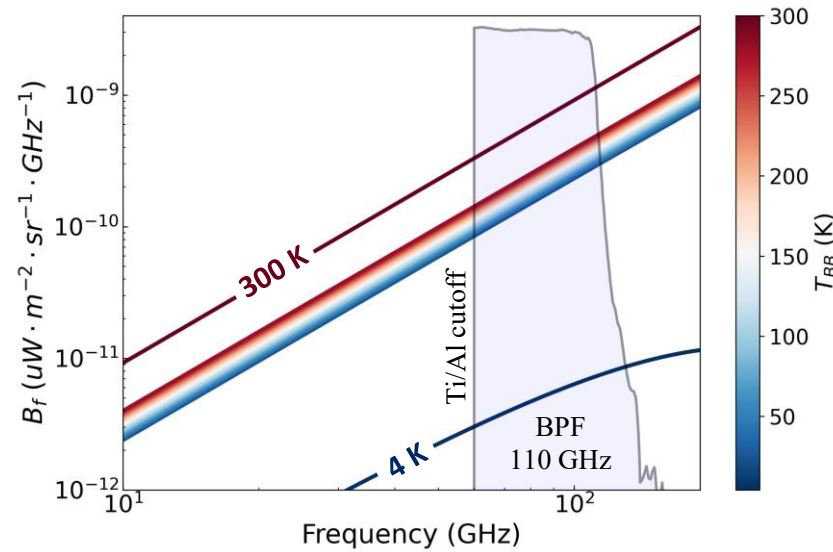
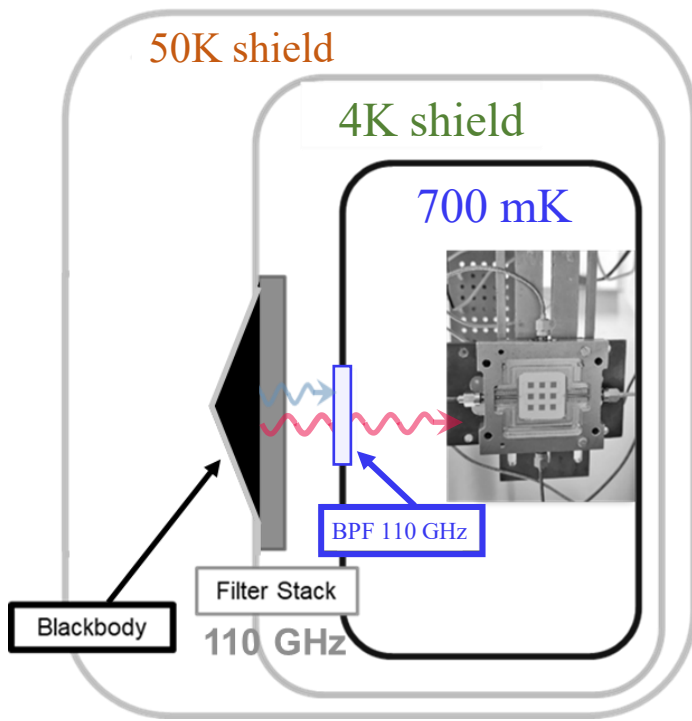
HWR : Half-Wave Resonators



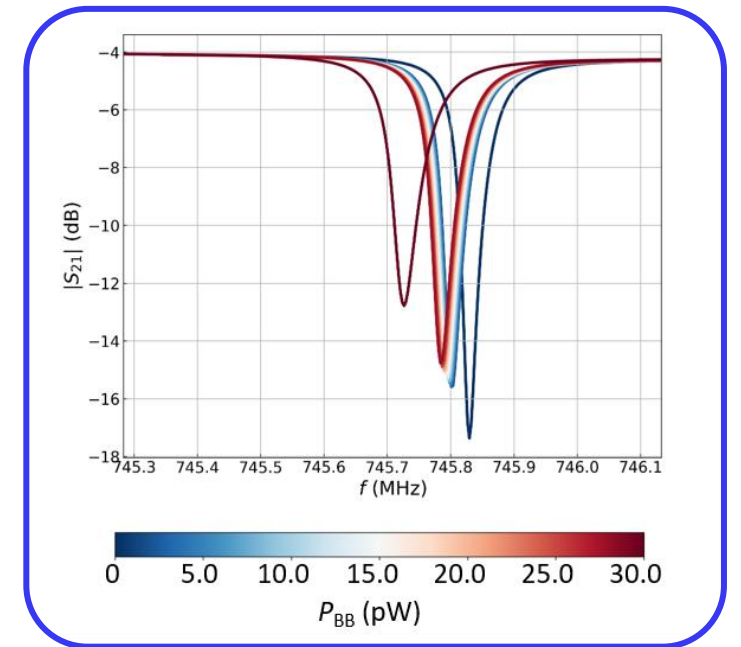
*Removing capacitor parasitic inductances reduces cross-polarization*

[10.48550/arXiv.2510.01882]

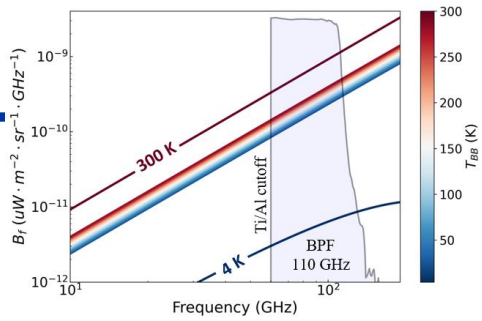
# Detector performance under optical load



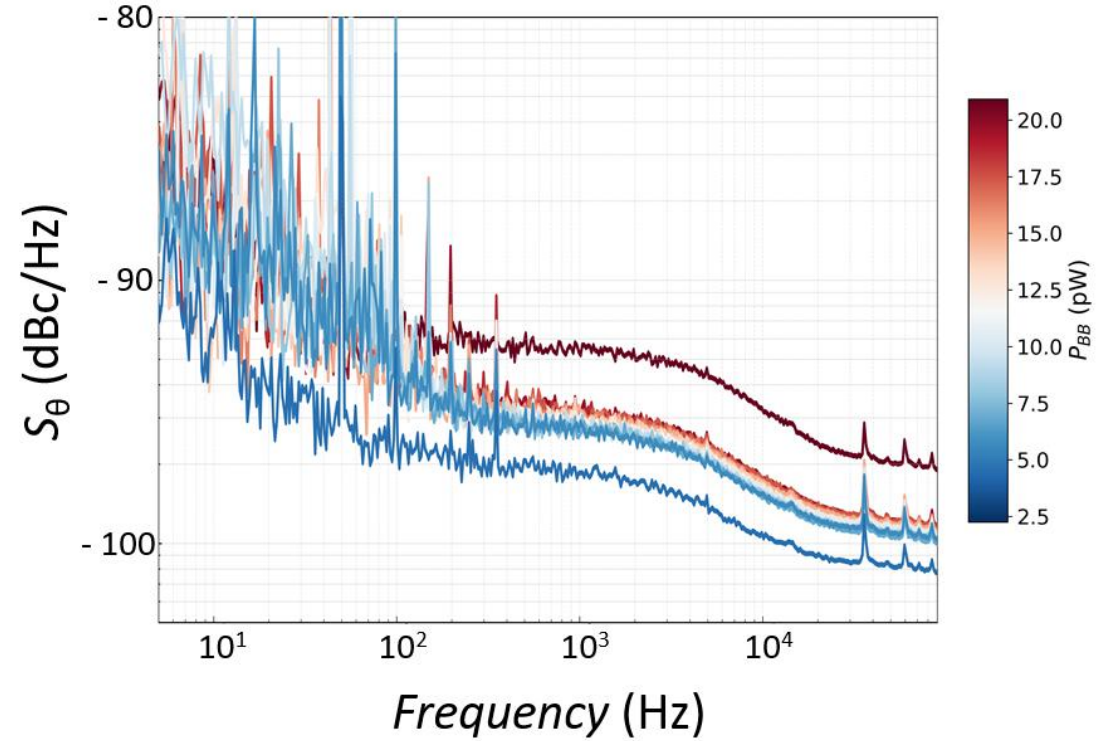
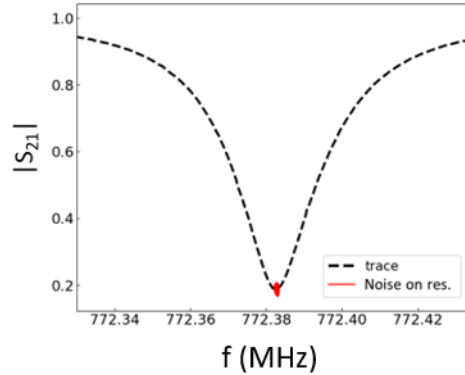
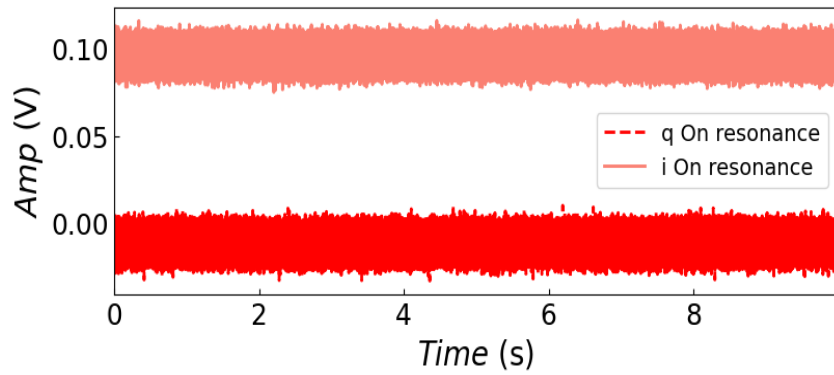
BB Temperature  
Absorbed power mapping



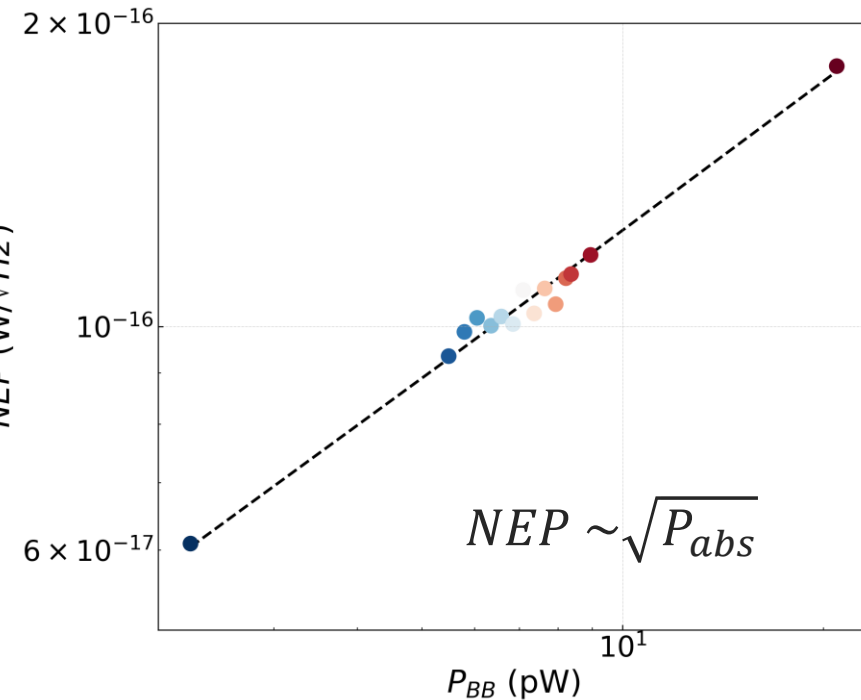
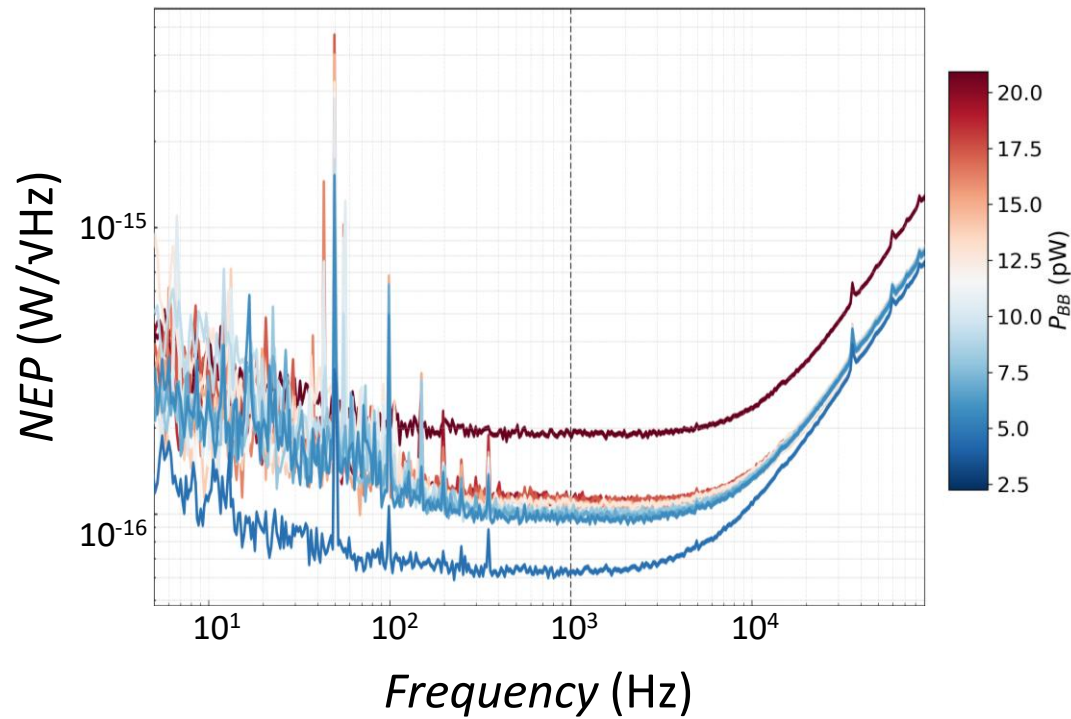
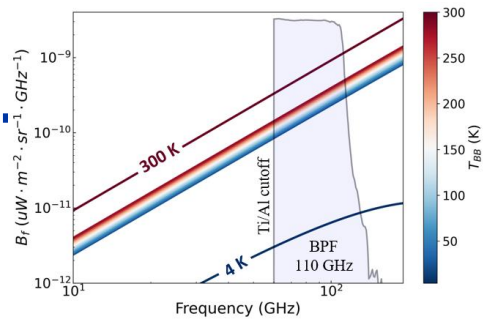
# Detector performance under optical load



*Power Spectral Density (PSD) reveals dynamic processes that introduce readout **noise***



# Detector performance under optical load



**Background limited**

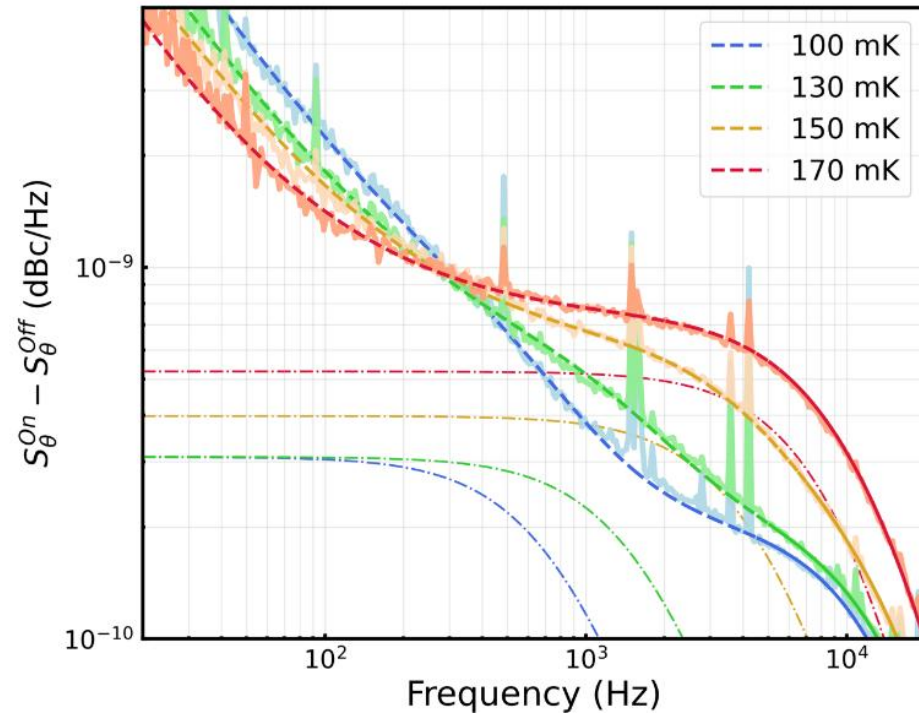
*Detector sensitivity follows photon arrival statistics*

# Detector sensitivity in low background

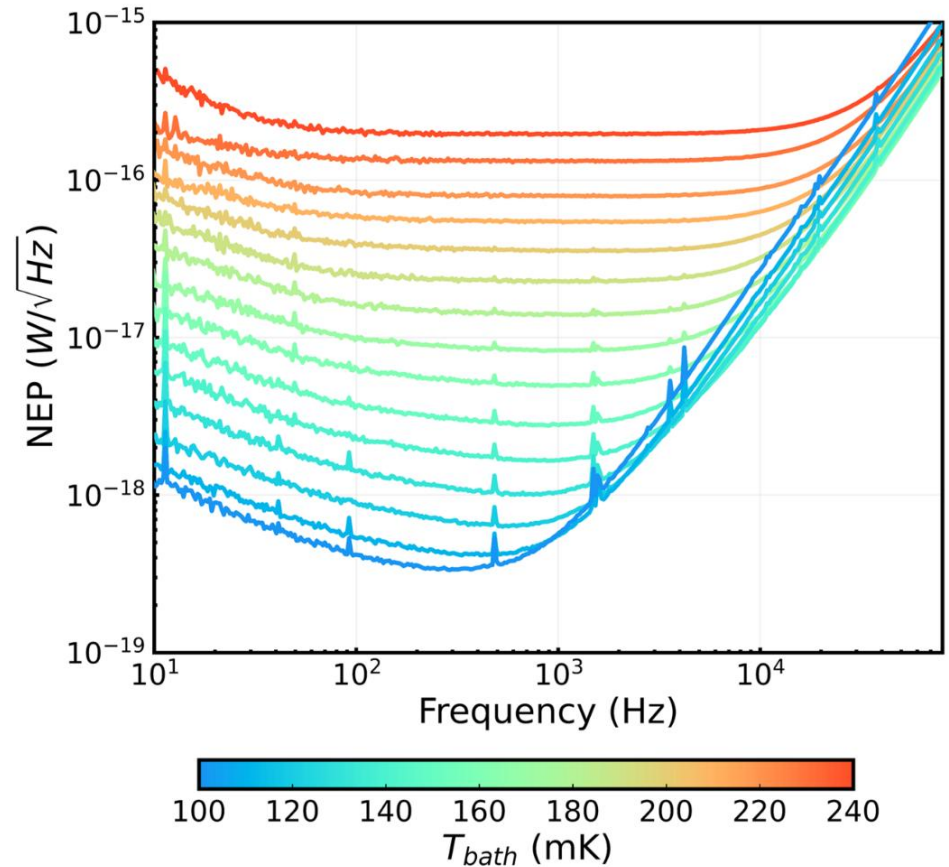
## Electrical Sensitivity

V. Rollano et al., IEEE Trans. Appl. Supercond. 36(6), 2026

### Power Spectral Density



$\delta\theta/\delta P$



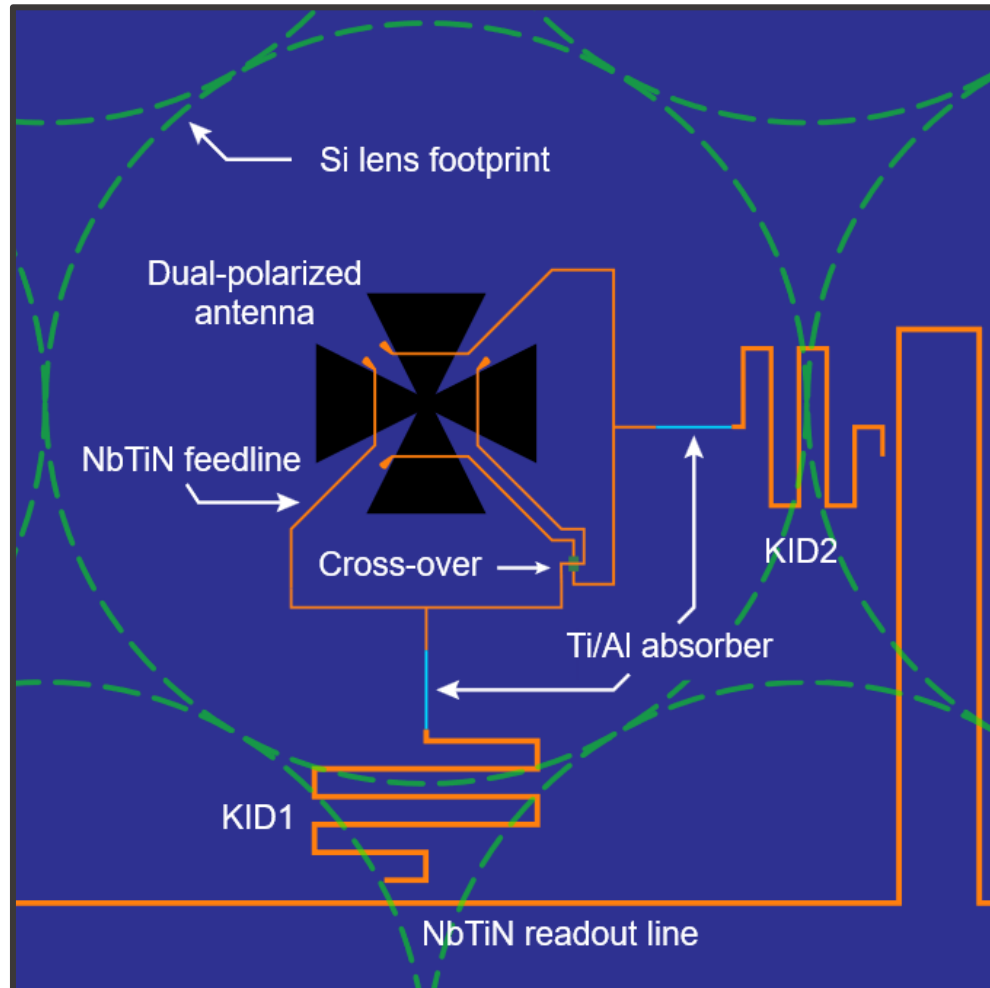
- $1/f$  excess noise at low frequencies
- QP noise in the flat region

$NEP(\text{dark}) \approx 3 \times 10^{-19} \text{ W}/\sqrt{\text{Hz}}$

# Next – generation detectors for the W-band

## *Antenna-coupled KIDS: architecture overview*

### *One-pixel design*



- *Silicon lensing layer for wavefront control*
- *Polarization discrimination with two orthogonal antennas*
- *Titanium/Aluminum absorbers for W-band*
- *Ti/Au and Al/Ti/Au for lower frequency bands*
- *NbTiN for signal transport and multiplexing readout*
- *Lower volume higher sensitivity*

*Efficient **polarization-selective** coupling of mm-wave axion signals to **superconducting KIDs***

# Current instruments and future missions



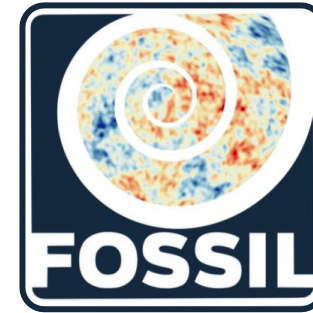
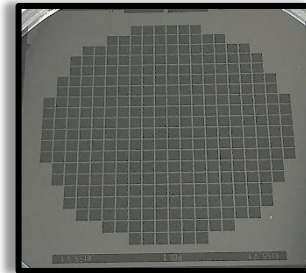
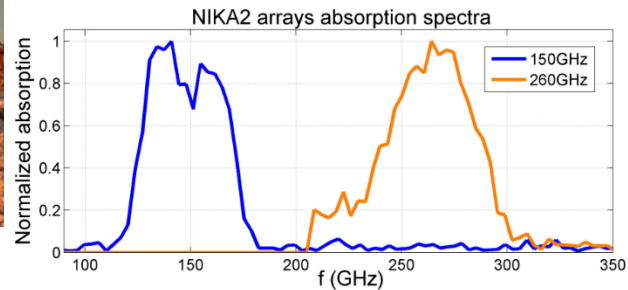
## NIKA 2 – IRAM 30 m Granada

1020 KIDs @ 2 mm

1140 KIDs @ 1.15 mm x 2 polarizations



*L. Perotto A&A (2020)*



FTS satellite for the study of **f**Or CMB  
**S**pectral di**S**tortion exp**L**oration  
*ESA M8 medium-sized mission*



**L**ite satellite for the study of **B**-mode  
polarization and **I**nflation from cosmic  
background **R**adiation **D**etection



## Future ground-based facility

50 m  
Wide FoV  
Large-format arrays



*Thanks for your attention!!!*

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*vrollano@cab.inta-csic.es*



CENTRO DE ASTROBIOLOGÍA · CAB  
ASOCIADO AL NASA ASTROBIOLOGY PROGRAM



**Superconducting  
Technologies Group**

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EXCELENCIA  
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OCHOA  
2017-2021



